

CLINICAL STUDIES

Comparison of Cardiac Catheterization and Doppler Echocardiography in the Decision to Operate in Aortic and Mitral Valve Disease

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Clinical decisions utilizing either Doppler echocardiographic or cardiac catheterization data were compared in adult patients with isolated or combined aortic and mitral valve disease. A clinical decision to operate, not operate or remain uncertain was made by experienced cardiologists given either Doppler echocardiographic or cardiac catheterization data. A prospective evaluation was performed on 189 consecutive patients (mean age 67 years) with valvular heart disease who were being considered for surgical treatment on the basis of clinical information. All patients underwent cardiac catheterization and detailed Doppler echocardiographic examination.

Three sets of two cardiologist decision makers who did not know patient identity were given clinical information in combination with either Doppler echocardiographic or cardiac catheterization data. The combination of Doppler echocardiographic and clinical data was considered inadequate for clinical decision making in 21% of patients with aortic and 5% of patients with mitral valve disease. The combination of cardiac catheterization

and clinical data was considered inadequate in 2% of patients with aortic and 2% of patients with mitral valve disease. Among the remaining patients, the cardiologists using echocardiographic or angiographic data were in agreement on the decision to operate or not operate in 113 (76% overall).

When the data were analyzed by specific valve lesion, decisions based on Doppler echocardiography or catheterization were in agreement in 92%, 90%, 83% and 69%, respectively, of patients with aortic regurgitation, mitral stenosis, aortic stenosis and mitral regurgitation. Differences in cardiac output determination, estimation of valvular regurgitation and information concerning coronary anatomy were the main reasons for different clinical management decisions. These results suggest that for most adult patients with aortic or mitral valve disease, alone or in combination, Doppler echocardiographic data enable the clinician to make the same decision reached with catheterization data.

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Studies (1-6) comparing cardiac catheterization and Doppler echocardiography in the evaluation of the severity of aortic and mitral valve disease have usually shown excellent correlations. However, these investigations have been more concerned with comparing specific hemodynamic measurements than with comparing clinical management decisions made on the basis of information obtained with either technique alone. These hemodynamic comparisons are often made in the context of a study design that attempts to produce near simultaneous recordings under ideal technical conditions. Frequently, only selected patients with isolated

valve disease are enrolled. The extent to which Doppler echocardiography can replace cardiac catheterization in the evaluation of patients with valvular heart disease cannot be realistically assessed under such artificial circumstances (6-10).

Even the few studies (11) that compared management decisions reached after Doppler echocardiography or catheterization suffer from strict exclusion criteria and a rigidly assigned decision-making matrix that may not reflect the complexity of many clinical circumstances or the nuances inherent in the medical decision-making process.

The purpose of this study was to determine the extent of agreement about the decision to operate on patients with isolated or combined aortic and mitral valve disease when experienced cardiologists are given clinical information and Doppler echocardiographic data alone or the same clinical information and cardiac catheterization data alone. No attempt was made to exclude patients with technically difficult

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Doppler studies, coexistent coronary artery disease or additional medical problems, including previous open heart surgery. Rather, in a large group of consecutive patients referred for evaluation of valvular heart disease, we sought to correlate the decisions made using each method alone and determine possible reasons for any differences found in the final management decisions.

Study patients. Between August 1, 1987 and September 1, 1988, 189 patients were referred to the cardiac catheterization laboratory for evaluation of aortic or mitral valve disease, or both. All 189 patients referred by their private physicians to the cardiac catheterization laboratory underwent M-mode, two-dimensional and Doppler echocardiography. The time span between cardiac catheterization and echocardiographic examination ranged from 0 to 73 days (mean 8 ± 15). In no patient were the two procedures simultaneously performed. There were 88 men and 101 women whose age ranged from 32 to 91 years (mean 67 ± 11). Among the aortic valves evaluated, there were 4 mechanical and 13 porcine prostheses. Among the mitral valves, there were 3 mechanical and 13 porcine prostheses. Ninety-four patients were referred for evaluation of aortic valve disease, 32 for combined aortic and mitral valve disease and 63 for mitral valve disease.

The physician decision makers generating the decisions reported in this study had no influence on the actual management decision made by the referring physician. They also had no knowledge of the patient's outcome. In many cases, the referring physician had obtained echocardiographic evaluation before sending the patient for cardiac catheterization and the study group is biased to the extent that patients without significant valvular disease were not referred for catheterization and were, therefore, not candidates for enrollment in this study. Similarly, patients who underwent valve surgery without cardiac catheterization were not included. The comparisons between echocardiography and catheterization were largely confined to patients who were referred for invasive evaluation because the referring physician believed that the patient was a possible candidate for operation.

Clinical information. The clinical information recorded for each patient included a detailed cardiovascular history and physical examination, as well as a description of significant coexisting medical conditions. Also included was an interpretation of the electrocardiogram and chest X-ray film obtained at the time of cardiac catheterization. For the most part, these data formed the clinical basis that prompted referral for cardiac catheterization and possible operation.

For purposes of classifying patients and assessing the frequency with which clinical information alone could be used with confidence to determine a management decision, three physicians involved in the study reviewed the clinical information without knowledge of the catheterization or echocardiographic findings. They determined the type of valve lesion present in each patient and assigned the patient to one of three management categories: operation, no oper-

ation or uncertain. The latter category was chosen if additional catheterization or echocardiographic evaluation, or both, was required before a management decision could be made.

Doppler Echocardiography

Studies were performed with a variety of commercially available Doppler echocardiographic systems routinely used in our echocardiography laboratory. M-mode and two-dimensional echocardiography and Doppler color flow imaging were performed from the parasternal long- and short-axis and apical, subxiphoid, right parasternal and suprasternal windows. Chamber sizes were recorded and tabulated. Motion of the left ventricular walls was graded semiquantitatively as hyperkinetic; normal; mildly, moderately or severely hypokinetic; akinetic; dyskinetic or abnormal (for example, consistent with conduction abnormalities or previous cardiac surgery). Valvular morphology was observed and tabulated. This included the presence or absence of a prosthesis, leaflet thickening, stenosis, calcification, prolapse, flail leaflet, vegetations or other masses.

Doppler echocardiography. Pulsed and continuous wave Doppler examinations were performed from the apical window. In cases of aortic stenosis, continuous wave Doppler recording was also performed from the right parasternal and suprasternal windows. The diagnostic quality of each study was graded on a scale from 1 (highest quality, all echocardiographic views and Doppler envelopes clearly and completely seen) to 4 (poorest quality, incompletely seen views). Of the 189 echocardiographic studies performed, 134 (71%) were considered excellent, 44 (23%) good, 9 (5%) fair and 2 (1%) poor. Each Doppler echocardiographic study was read by a group of at least three members of the echocardiography laboratory. Final interpretations were determined by consensus.

Aortic stenosis. Transaortic pressure gradient was determined by continuous wave Doppler evaluation in the apical, right parasternal and suprasternal views. The fastest flow velocity was used for calculation. The envelope of the spectral analysis was manually traced on a digitizing tablet and the peak and mean transaortic valve gradients were calculated by a computer program (Sony Cardiology Analysis System) using the modified Bernoulli equation (pressure gradient = $4 \times \text{velocity}^2$). When the parasternal long-axis image was clear enough to obtain a reliable left ventricular outflow tract diameter and the left ventricular outflow tract flow velocity tracing was adequate, aortic valve area was calculated by using the law of continuity.

Aortic and mitral regurgitation. The width and length of the color flow jet into the left ventricle or left atrium on the parasternal and apical views were used to determine the grade of aortic or mitral regurgitation, respectively. In addition, aortic regurgitation grading also utilized analysis of the rate of decrease in aortic regurgitant jet velocity as observed by continuous wave Doppler ultrasound. When

possible, the pulsed Doppler spectral tracing in the proximal descending thoracic aorta was also analyzed.

Mitral stenosis. Mean and end-diastolic mitral pressure gradient were calculated with use of the modified Bernoulli equation. Mitral valve area was calculated from the continuous wave ultrasound tracing with use of the pressure half-time method (12).

Cardiac Catheterization

Cardiac catheterization was performed in all patients and the diagnostic quality of each study was considered to be of good or excellent quality. Right and left heart pressures were measured. Cardiac output was determined by the Fick technique. All patients underwent coronary angiography. Left ventricular angiography was performed and regional wall motion analyzed. Aortography was performed in all patients except when severe aortic stenosis was found in the absence of a murmur of aortic regurgitation.

Each study was interpreted at the daily morning conference by the five cardiologist members of the cardiac catheterization laboratory. Final interpretations were arrived at by consensus.

Aortic valve disease. Peak to peak and mean transaortic valve systolic pressure gradients were determined by pull-back or simultaneous aortic and left ventricular pressure measurements, or both. Aortic valve area was calculated with use of the Gorlin formula unless aortic regurgitation was present.

The severity of aortic regurgitation was graded as absent, mild, moderate or severe according to established angiographic standards.

Mitral valve disease. The transmitral valve gradient was evaluated by simultaneous recording of pulmonary capillary wedge and left ventricular pressures or left atrial and left ventricular pressures if transseptal catheterization was used. The transseptal technique is usually performed in our laboratory to determine the transmitral pressure gradient. Mitral valve area was determined with use of the Gorlin formula.

Left ventricular angiography was performed to evaluate left ventricular function and to determine the degree of mitral regurgitation. Mitral regurgitation was graded as absent, mild, moderate or severe.

Left ventricular wall motion. The left ventricular perimeter was divided into seven segments and regional wall motion was qualitatively assessed over a range from hyperkinetic to dyskinetic.

Coronary angiography. Coronary angiography was performed in multiple projections. Coronary stenoses were graded as mild, moderate or severe in each of the major arteries and all major branches. The results of coronary angiography for a given patient were provided to the physicians evaluating clinical information and cardiac catheterization data alone, but not to the physicians evaluating clinical information and echocardiographic data alone.

Clinical Decision

Decision-maker groups. There were three groups of clinician decision makers. All were board-certified cardiologists with daily clinical responsibilities. Each group comprised a member of the echocardiography laboratory and a member of the catheterization laboratory. Two forms were generated for each patient for purposes of decision making. The first contained the clinical information and Doppler echocardiographic data and was designated "ECHO." The second contained the same clinical information and cardiac catheterization data and was designated "CATH." Thus, each group of two decision makers analyzed two sets of data for each patient at different times in random order. They had no knowledge of either the identity of the patient being studied or the data obtained by the alternate method and the decision reached by the other two groups of decision makers.

The management decision was reached by agreement within each group of two cardiologists and was entered as one of three decisions: 1) no intervention required for the valve; 2) surgical intervention required, including replacement, repair or percutaneous balloon valvuloplasty; and 3) decision uncertain. The latter choice was made when more information was believed to be necessary to reach a definitive decision. Additional information might include invasive angiographic or hemodynamic measurements, noninvasive studies including echocardiographic or radionuclide examinations or more clinical data.

The decision used for statistical comparison between catheterization-based and echocardiography-based recommendations was either the unanimous decision of all three groups or the majority decision of two of three groups. If a majority decision could not be reached (that is, one group recommended operation, another no intervention and the third was uncertain), the form was submitted to a fourth "moderator" group whose decision was then used for purposes of comparison. When a difference was found between the management decision arrived at by echocardiography or catheterization, the data provided by each method were carefully reviewed and the possible reasons for the difference explored.

Clinical factors affecting decision making. We purposely did not define strict criteria for the decision to operate or not operate on a given patient. Few physicians actually make clinical decisions on the basis of strict criteria, but rather weigh a variety of factors before deciding to refer a patient for heart surgery. In addition to the hemodynamic data, age, coexisting medical conditions and extent of previous medical treatment all enter into the decision-making process. For example, replacement of a moderately stenotic aortic valve (valve area 1.1 cm², mean pressure gradient 35 mm Hg) might be recommended to a patient with severe angina and advanced coronary artery disease because coronary bypass surgery is required and later surgery for aortic valve replacement can be avoided. A firm rule to operate only on patients

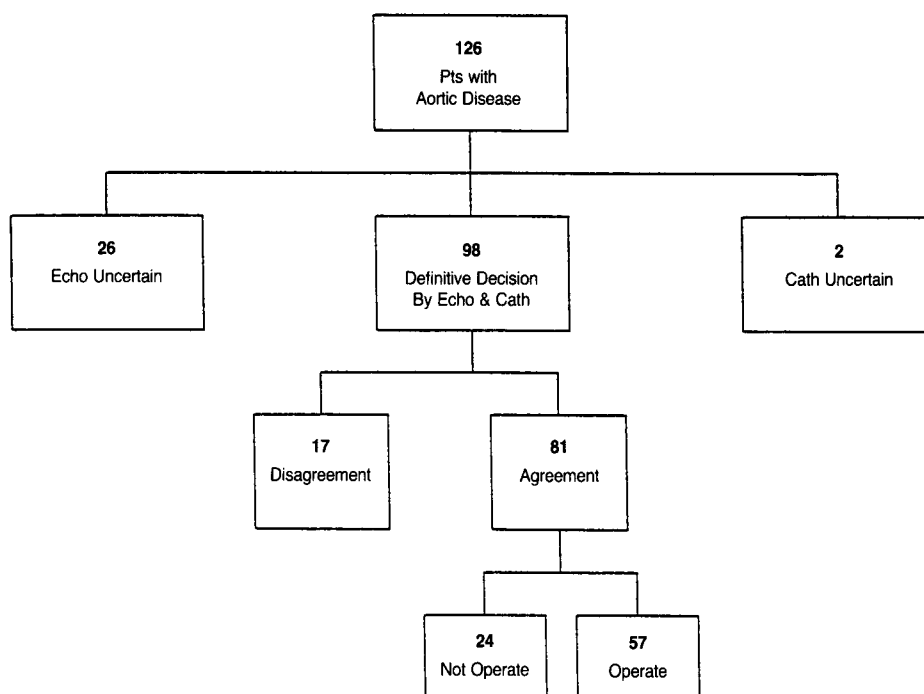


Figure 1. Analysis of clinical decision making in 126 patients (Pts) with aortic valve disease. Cath = cardiac catheterization; Echo = echocardiography.

with an aortic valve area $<1 \text{ cm}^2$ would not reflect the circumstances involved in the decision to replace this patient's aortic valve. Thus, rather than adopt a decision-making strategy that was potentially unrealistic, we allowed the physician decision makers to follow their usual clinical practice. Because three separate groups of two cardiologists rendered a judgment, we believe the resulting decision represents an average standard of practice in the medical community.

Interobserver variability. Interobserver variability was determined by analyzing the differences in the decisions made for a given patient and method by each of the three groups.

Intraobserver variability. Forty studies chosen at random were resubmitted to the same group for reinterpretation without knowledge of their previous interpretation. These studies form the basis of analyses of intraobserver variability.

Statistical analysis. Continuous variables are presented as the mean values \pm SD. Percentages were calculated in the usual manner and the kappa statistic was calculated to evaluate the concordance between the two methods and between each method and chance. The kappa statistic measures the observed agreement adjusted for the agreement expected by chance alone. Values for kappa range from -1 to $+1$. A kappa of 0 is the agreement expected by chance and kappa values >0.80 are generally believed to represent excellent agreement, 0.40 to 0.80 moderate agreement, 0.20 to 0.40 fair agreement and <0.20 poor agreement (13,14).

Results

A decision to operate or not operate was reached by both echocardiography and catheterization for both valves in 148 (78%) of the 189 patients. Among these 148 patients, the decisions reached by echocardiography and catheterization were in agreement in 113 patients (76%). The presumed reasons for differences are outlined in the subgroup analysis.

Subgroup Analysis: Aortic Valve Disease

There were 126 patients referred for isolated aortic or combined aortic and mitral valve disease (Fig. 1). In these patients, a definitive clinical decision to operate or not operate was reached by both methods in 98 cases (77%). In 81 (83%) of these 98 cases, the decision reached by echocardiography was not changed by catheterization data. These decisions included a decision to operate on 57 aortic valves and a decision not to operate on 24 aortic valves.

Uncertain decisions by echocardiography. In 26 cases (21%), the decision reached by echocardiography was uncertain; more information was needed to make a decision than could be provided by echocardiography alone. In these cases, the additional information was almost always provided by cardiac catheterization. Left heart pressures were requested in 22 cases, cardiac output in 17, coronary angiography in 15, aortic root angiography in 9, right heart pressures in 10, left ventricular angiography in 3 and more clinical data in 1. (More than one type of additional information was requested in many cases.)

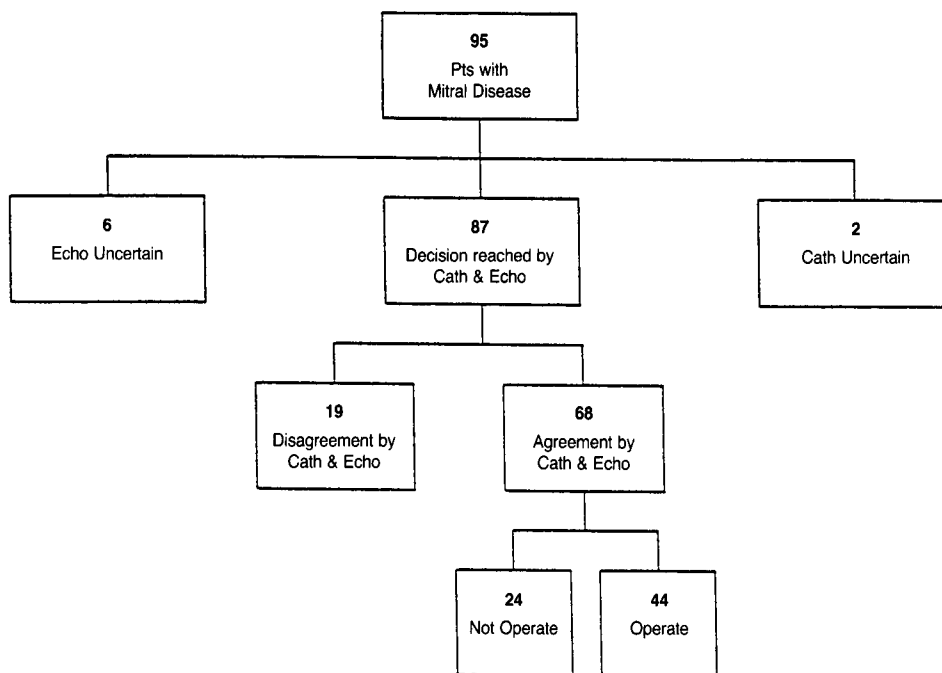


Figure 2. Analysis of clinical decision making in 95 patients with mitral valve disease. Abbreviations as in Figure 1.

In two cases (2%), more information was needed to make a decision than could be provided by catheterization alone. In both cases, an exercise gated pool scan was requested and in one case, a Holter monitor was also requested.

Discrepant decisions. In 17 (17%) of the 98 cases in which a definite decision was reached by both methods, the decision made by echocardiography differed from that made by catheterization. In five patients with predominantly aortic regurgitation or mixed stenosis and regurgitation, a difference in the quantification of the amount of regurgitation appeared responsible for the discrepant management decision. Catheterization described more severe regurgitation in two patients and echocardiography suggested more severe regurgitation in two patients. In a fifth patient, both methods described severe aortic regurgitation, but echocardiographic analysis documented normal left ventricular dimensions that resulted in a decision for no intervention.

In 6 of 12 patients with predominant aortic stenosis, a difference in cardiac output measured at catheterization appeared to account for the different management decision. In four of these six patients, a high cardiac output at catheterization resulted in a decision not to operate. In two of these four patients, the pressure gradient measured by both methods was virtually identical. A low cardiac output at catheterization resulted in a decision to operate on two patients, although a difference in valve gradient also may have contributed to the altered management decision in one of these patients. In two patients, variation in valve gradient measurements alone appeared to be responsible for the difference in management. Both valve gradients were in the 30 to 50 mm Hg range.

In one patient, the presence of severe left main stenosis at

catheterization in association with moderate aortic stenosis accounted for the difference in management. In another patient, more severe mitral stenosis described at catheterization than on echocardiography influenced the decision to replace a moderately diseased aortic valve at operation. In two patients, no obvious reason for the management difference could be found. It should be remembered that these discrepancies related to clinical decisions rather than hemodynamic measurements.

Subgroup Analysis: Mitral Valve Disease

There were 95 patients referred for isolated mitral or combined aortic and mitral valve disease (Fig. 2). In these patients, a definitive clinical decision to operate or not operate was reached by both methods in 87 cases (92%). In 68 (78%) of these 87 cases, the decision reached by echocardiography was not changed by catheterization. These decisions included a decision to operate on 44 valves and a decision not to operate on 22 valves.

Uncertain decisions by echocardiography. In six cases (6%), more information was needed to make a decision than could be provided by echocardiography alone and appropriate management was considered uncertain. In all cases, the additional information requested was provided by cardiac catheterization. Right heart pressures were requested in five cases, left heart pressures in four, cardiac output in four, left ventricular angiography in five, aortic root angiography in two, right ventricular angiography in two and coronary angiography in one.

Discrepant decisions. In 19 (21%) of the 87 patients with isolated mitral valve disease in whom a definite decision was

Table 1. Comparison of Management by Doppler Echocardiography and Cardiac Catheterization in Patients With Aortic Stenosis, Aortic Regurgitation and Mixed Valve Disease

	No. of Pts	Decision			Agreement	
		DEF	EU	CU	Agree	Disagree
AS	94	73	20	1	61	12
AR	16	12	3	1	11	1
AS/AR	16	13	3	0	9	4

AR = aortic regurgitation; AS = aortic stenosis; AR/AS = mixed valve disease; CU = catheterization decision uncertain; DEF = definitive decision by Doppler echocardiography and cardiac catheterization; EU = echocardiographic decision uncertain; Pts = patients.

reached by both methods, the decision made by echocardiography differed from that made by catheterization. In 15 (79%) of these 19 patients, the basis for the disagreement was a difference in the grading of mitral regurgitation by echocardiography compared with catheterization. In six patients, mitral regurgitation determined by Doppler echocardiography was more severe and in nine patients it was less severe than that determined by cardiac catheterization. In three patients, the two methods were in agreement on the severity of the valve lesions but in disagreement regarding management. In one patient, aortic stenosis was judged more severe by catheterization than by echocardiography although both methods determined only moderate mitral valve disease, and a decision was made to perform elective repair of the mitral valve during the recommended aortic valve surgery.

Comparison by Clinically Suspected Valve Lesion

Another way to compare the management decisions reached by catheterization and echocardiography is to analyze the study patients in terms of the valve lesion suspected to be the most clinically significant.

Aortic stenosis. There were 94 patients with clinically suspected isolated aortic stenosis (Table 1). In 73 (78%) of these 94 patients, a definitive decision to operate or not operate was reached by both echocardiography and catheterization. The two methods were in agreement on the decision in 61 patients (84%) and in disagreement in 12 (16%). The reasons for disagreement have been detailed in the subgroup analysis for aortic valve disease. In 20 cases, the decision by echocardiography was uncertain with addi-

tional information requested and in 1 case, the decision by catheterization was uncertain.

Aortic regurgitation. There were 16 patients with clinically suspected isolated aortic regurgitation (Table 1). In 12 (75%) of these 16, a decision was reached by both echocardiography and catheterization. The two methods were in agreement in 11 cases (92%) and in disagreement in 1 case (8%). As previously described, the reason for disagreement was the severity of regurgitation quantitated by each method. In three patients, the decision by echocardiography was uncertain and in one patient the decision by catheterization was uncertain.

Mixed aortic stenosis and regurgitation. Sixteen patients had a clinical diagnosis of mixed aortic valve disease (Table 1). In 13 (81%) of these 16, a decision was reached by both methods; the two methods were in agreement in 9 (69%) and in disagreement in 4 patients (31%). Differences in the severity of regurgitation described by each method accounted for the differences. In three patients, the decision by echocardiography was uncertain.

Mitral stenosis. There were 23 patients with clinically suspected mitral stenosis (Table 2). In 21 (90%) of these 23, a decision to operate or not operate was reached by both methods; the two methods were in agreement in 19 patients (90%) and in disagreement in 2 (10%). In the two latter patients, the severity of mitral stenosis described was similar, but in one patient more severe aortic stenosis described by catheterization dictated a decision to operate simultaneously on the mitral valve; in the other case, there was no apparent reason for the discrepancy in management decision. In one patient with isolated mitral stenosis, the decision by echocardiography was uncertain and in one patient the decision by catheterization was uncertain.

Table 2. Comparison of Management by Doppler Echocardiography and Cardiac Catheterization in Patients With Mitral Stenosis, Mitral Regurgitation and Mixed Valve Disease

	No. of Pts	Decision			Agreement	
		DEF	EU	CU	Agree	Disagree
MS	23	21	1	1	19	2
MR	56	52	3	1	36	16
MS/MR	16	14	2	0	13	1

MR = mitral regurgitation; MS = mitral stenosis; MS/MR = mixed mitral valve disease; other abbreviations as in Table 1.

Table 3. The Calculated Kappa (k) Statistic Listed in Decreasing Magnitude, Its Determinants and Confidence Interval

Lesion	Kappa (k)	Pts With Management Agreement	Total No. of Pts	Po	Pc	95% Confidence Interval
AR	0.83	11	12	0.92	0.50	$0.61 \leq k < 1.00$
MS	0.69	19	21	0.90	0.69	$0.46 < k < 0.92$
AS	0.65	61	73	0.84	0.55	$0.51 < k < 0.77$
MS/MR	0.63	13	14	0.93	0.81	$0.32 < k < 0.94$
MR	0.38	36	52	0.69	0.50	$0.20 < k < 0.56$
AS/AR	-0.13	9	13	0.69	0.73	$-0.61 < k < 0.35$

Values for the number of patients are different from those in Tables 1 and 2 because for purposes of calculation of the kappa statistic, patients with an uncertain decision were not included in the statistical comparison. Pc = agreement expected by chance; Po = observed proportion of agreement; other abbreviations as in Tables 1 and 2.

Mitral regurgitation. In 56 patients, isolated mitral regurgitation was clinically diagnosed (Table 2). In 52 (93%) of the 56 patients, a decision was reached by both echocardiography and catheterization. The two methods were in agreement in 36 patients (69%) and in disagreement in 16 (31%). In almost every case, the reason for disagreement was related to the severity of regurgitation described by each method. Each disagreement was significant enough to alter the decision to operate or not operate on the mitral valve. In three cases, the decision by echocardiography was uncertain and in one case, the decision by catheterization was uncertain.

Mixed mitral stenosis and regurgitation. Sixteen patients had clinically suspected mixed mitral valve disease. In 14 (88%) of the 16 patients, a decision was reached by both methods; the two methods were in agreement in 13 (93%) of the 14 patients. In two patients the decision reached by echocardiography was uncertain.

Statistical analysis. Calculation of the kappa statistic is presented in Table 3. This statistic measures the observed amount of agreement between the two methods adjusted for the amount of agreement expected by chance alone. The highest kappa value was for aortic regurgitation and the lowest for mixed aortic valve disease, but the 95% confidence interval for the latter was quite wide because of the small number of patients in that group. The kappa statistic is generally quite sensitive to small patient numbers. Despite a large number of patients, however, the kappa value for agreement between catheterization and echocardiography in

patients with isolated mitral regurgitation was low, reflecting the relatively poor agreement between the two techniques.

Clinical Information

Management decisions based on clinical information alone are summarized in Table 4. For every valve lesion except mitral stenosis and mixed aortic stenosis and regurgitation, a definitive decision could not be made in the majority of cases on the basis of clinical information alone. In most cases, it was necessary to request cardiac catheterization or echocardiography, or both. As can be seen in Table 4, among patients for whom a decision to operate or not operate was made, the agreement between catheterization and echocardiography-based recommendations was fairly strong, although with the exception of patients with aortic stenosis and mitral stenosis, the number of patients compared was small.

Interobserver variability: aortic valves. There were 177 echocardiographic studies read by all three cardiologist groups. The other 12 studies were read by two of the three groups and both groups were in agreement. In 124 cases (70%), the decisions of all three groups were in agreement. In 41 cases (23%), two of the three groups agreed. In 12 cases (7%), one group believed that intervention was necessary, another believed that none was necessary and the third group was uncertain. These 12 cases were brought to arbitration.

Table 4. Management Decision Based on Clinical Information Alone and Comparison With Catheterization (Cath) and Echocardiographic (Echo) Management Decision

Diagnosis	No.	No. (%)	Management Decision Can Be Reached				Uncertain*
			Operate	Do Not Operate	% Agreement With Cath	% Agreement With Echo	No. (%)
AS	94	30 (32)	24	6	89	83	64 (68)
AR	16	6 (38)	5	1	83	83	10 (62)
AS/AR	16	9 (56)	9	0	100	75	7 (44)
MS	23	16 (70)	15	1	80	80	7 (30)
MR	56	4 (7)	4	0	100	75	52 (93)
MS/MR	16	4 (25)	4	0	100	100	12 (75)

*More information needed to reach decision. Abbreviations as in Tables 1 and 2.

There were 174 catheterization studies read by all three groups. Fifteen studies were read by two of the three groups and both groups were in agreement. In 140 cases (80%), the readings by all three groups agreed. In 26 cases (15%), two of the three groups agreed. The remaining eight cases (5%) were brought to arbitration because there was no agreement among the three groups.

Interobserver variability: mitral valves. There were 177 echocardiographic studies read by all three groups. In 129 cases (73%), the readings by all three groups agreed. In 40 cases (23%), readings by two of the three groups agreed. In eight cases (5%), one group believed that intervention was necessary, another believed that none was necessary and the third group was uncertain. These eight cases were brought to arbitration.

There were 174 catheterization studies read by all three groups. In 138 cases (79%), the readings by all three groups agreed. In 33 cases (19%), the readings of two of the three groups agreed. In three cases (2%), no agreement could be reached among the three groups. These three cases were brought to arbitration.

Intraobserver variability. To assess intraobserver variability, 41 echocardiographic studies were read twice by the same group without knowledge of previous readings. The two readings were in agreement on both valves in 34 cases (83%). In six cases, there was agreement regarding the mitral valve, but disagreement regarding the aortic valve. In all six cases, one reading was certain about the decision to operate or not operate on the aortic valve, whereas the other reading was uncertain. In one case, there was agreement regarding the aortic valve but disagreement regarding the mitral valve. In this case, a management decision was made during the initial reading, whereas the other reading was uncertain.

Similarly, 45 catheterization studies were read twice by the same group without knowledge of previous readings. The two readings were in agreement on both valves in 38 cases (84%). In four cases, there was agreement regarding the mitral valve, but disagreement regarding the aortic valve. In all four of these cases, one reading was certain about the decision to operate or not operate on the aortic valve, whereas the other reading was uncertain. In three cases, there was agreement regarding the aortic valve, but disagreement regarding the mitral valve. In one case, the first reading recommended surgical intervention, whereas the second recommended no surgical intervention; in the other two cases, the first reading reached a management decision, whereas the second was uncertain.

Discussion

It appears that the majority of patients could not be referred definitively for surgery on the basis of clinical information alone. This is not surprising given the low specificity of electrocardiography (ECG) and chest roentgenography in the diagnosis of valvular heart disease and the difficulties in judging with acceptable certainty the severity

of most valve lesions on the basis of the physical examination. With few exceptions, current practice requires that all patients with valvular heart disease undergo additional echocardiography or invasive evaluation, or both, before referral to surgery.

Doppler echocardiography versus cardiac catheterization. In this study, we compared Doppler echocardiography with cardiac catheterization in the clinical management of a large group of patients with isolated or combined aortic or mitral valve disease. Overall, there was agreement about the management decision for both valves in 76% of the cases, but the amount of disagreement varied depending on the specific valve lesion and was especially high in cases of mitral regurgitation. We did not design this investigation to determine whether Doppler echocardiography or cardiac catheterization is better at assessing the degree of valvular and cardiac disease because each technique measures the various components of cardiac function in a different way. Neither did we attempt to determine whether the "correct" clinical decision was made. We have no data on the surgical findings or clinical outcome in these patients and do not know if the recommendations of our cardiologist decision makers agreed with the referring physician's actual decision. Rather, we were interested to discover if one technique could be substituted for the other without altering the clinical management decision for patients with chronic valvular heart disease, and any information about patient outcome is not germane to that purpose. Likewise, we did not specifically assess the need to perform coronary angiography before valve surgery. We recognize the limitations of echocardiography in this regard and accept the need for preoperative coronary angiography in many older patients.

Previous investigations. Although many previous investigations (1-6,15) have compared hemodynamic measurements by Doppler echocardiography and cardiac catheterization, their study design has often been most concerned with optimizing the conditions for favorable comparisons and it remains to be seen whether the two techniques applied in a clinically realistic setting can approach uniformity in actual management decisions. If the accepted standard of practice is to favor or replace one technique with another, then one basis for adopting a new standard is that clinical management decisions are either improved or performed in a manner consistent with the more established technique, in this case, cardiac catheterization. To date, few reported investigations have examined this basic question.

Jaffe et al. (11) concluded in a comparison of clinical evaluation with Doppler echocardiography that the need for the assessment by cardiac catheterization could be avoided in most patients. They concluded that Doppler echocardiography made errors in only 7% of patients and that only one valve lesion would have been managed incorrectly on the basis of Doppler echocardiography alone. Our results suggest a greater discrepancy between the decisions made on the basis of Doppler echocardiography or cardiac catheterization alone.

Aortic stenosis. The current investigation demonstrates a basic concordance between catheterization and echocardiography in the decision to operate or not operate on patients with isolated aortic stenosis 84% of the time (61 of 73 cases). This contrasts with the finding of Jaffe et al. (11) that Doppler analysis committed no errors compared with catheterization in 34 patients with suspected significant aortic stenosis. The altered management decisions in our patients with isolated aortic stenosis were most often the result of a more confident measurement of cardiac output determined by cardiac catheterization or significant information about coronary anatomy and coexistent mitral valve disease described at catheterization but not on echocardiography. In an additional 21 cases of isolated aortic stenosis, echocardiographic evaluation resulted in an uncertain decision that in almost every case would have been clarified at catheterization. Although Miller (16) and others (17-20) concluded that the majority of patients with aortic stenosis do not require invasive hemodynamic measurements, our results show that approximately 15% of patients would be managed differently by Doppler echocardiographic analysis than by cardiac catheterization. What percent of these different management decisions would have led to adverse clinical outcomes is unknown.

Aortic regurgitation. In patients with isolated aortic regurgitation or mixed aortic stenosis and regurgitation in our study, the agreement between echocardiography and catheterization was 80% (20 of 25 patients), which is similar to the agreement seen in patients with aortic stenosis. The disagreements about management were almost always based on differences in the quantification of the severity of regurgitation, although in one case, information about left ventricular size obtained at echocardiography was pivotal. In general, the decision to operate for aortic regurgitation is more complicated than for aortic stenosis and measurements of contractility and ventricular geometry often play as important a role in the analysis as does the severity of regurgitation.

Mitral stenosis. In patients with isolated mitral stenosis or mixed mitral stenosis and regurgitation, the correlation between catheterization and echocardiography in the final management decision was strong. In 32 (91%) of 35 patients, the two techniques agreed and in the instances of disagreement, the Doppler echocardiographic and catheterization quantification of the severity of mitral stenosis were identical. Smith et al. (21) previously demonstrated a good correlation between Doppler analysis and catheterization in a retrospective comparison in patients with isolated mitral stenosis. Other reports (22), however, cautioned that in patients with decreased ventricular compliance, the pressure half-time method may overestimate the valve area and lead to errors in management. We did not directly measure left ventricular compliance in our patients, but also could not identify a group of patients with mitral stenosis in which a major discrepancy existed between the management decisions made by catheterization and echocardiography.

Mitral regurgitation. The subgroup with the greatest disagreement between the clinical management recommended by catheterization and echocardiography comprised patients with isolated mitral regurgitation. In 52 (93%) of 56 patients, the physicians analyzing the echocardiographic findings were confident enough concerning the data to recommend a definitive management decision. This was a higher degree of certainty than was found for aortic valve disease, where a definite decision was reached in 77% of patients. Despite a higher degree of confidence about the ability to make a decision in patients with isolated mitral regurgitation, agreement between the two techniques occurred in only 36 (69%) of the 52 patients. Disagreement was usually based on differences concerning the severity of regurgitation quantified at echocardiography and catheterization. Compared with catheterization, echocardiography demonstrated more severe regurgitation in six cases and less severe regurgitation in nine cases. In one case, echocardiographic information about left ventricular size appeared to be the reason for the discrepancy.

This larger disagreement between cardiac catheterization and echocardiography for cases of isolated mitral regurgitation is in some ways not surprising. Both angiographic and Doppler methods are imprecise and sensitive to variations in technique and loading conditions. In addition, each method measures a different variable: left atrial blood flow velocity distribution in the case of Doppler echocardiography and estimation of regurgitant flow volume with angiography. Unfortunately, attempts to quantitate regurgitant stroke volume or regurgitant fraction by either echocardiography or catheterization have not been highly successful because small errors in stroke volume determinations result in large errors in the calculation of regurgitant fraction (23-30). Our data differ from those of Jaffe et al. (11), who found that Doppler echocardiography agreed with the catheterization findings in all 13 patients with isolated mitral regurgitation, but overestimated the degree of regurgitation in 2 patients with associated mitral stenosis, a mistake that did not lead to a management error. It should be noted, however, that many patients with mitral regurgitation in our series also had aortic valve disease.

Left ventricular contrast angiography may overestimate mitral regurgitation when the injection site is near the valve or when the ventriculogram is performed using a transseptal anterograde approach with a catheter across the mitral valve. Ventricular arrhythmia during the injection of contrast medium may induce mitral regurgitation. A markedly dilated atrium may produce underestimation of the degree of mitral regurgitation.

Transthoracic echocardiography may underestimate mitral regurgitation in patients with a prosthetic valve as a result of left atrial "masking" or "shadowing." Transesophageal echocardiography (not performed on patients in this study) is now known to provide better evaluation of prosthetic mitral regurgitation (31). We estimated the degree of mitral regurgitation mainly by the area of the regurgitant jet

observed with Doppler color flow. It has been suggested that better estimation may be obtained when the regurgitant jet area is expressed as a percent of the left atrial area. However, a recent report (26) suggested that such estimation of jet area as a percent of left atrial area did not add sensitivity to the correlation between echocardiography and catheterization in the evaluation of the severity of mitral regurgitation.

Clinical implications. This investigation was more concerned with actual clinical management decisions made on the basis of echocardiography and catheterization than with hemodynamic comparisons of the two techniques. Although there was generally good correlation between both methods in the management of patients, important disagreements did occur. It is not realistic to expect 100% agreement between the two techniques because intraobserver variability in our study ranged from 3% to 11%, depending on the method and the valve lesion. However, if one accepts cardiac catheterization as the "gold standard," our data suggest that management differences may occur in 10% to 15% of patients with aortic valve disease, including isolated aortic stenosis, and as many as 30% of patients with isolated mitral regurgitation. The decision about whether to perform cardiac catheterization in a patient with valvular heart disease depends on a number of factors, including the clinical presentation, confidence in the technical quality of the Doppler echocardiographic study and relative risk of cardiac catheterization. It should be remembered, however, that recommendations not to perform catheterization routinely based on studies showing favorable hemodynamic comparisons between the two techniques are not directly confronting data about the frequency of clinical management differences that one can expect from such an approach. There are relatively few published studies that directly compare the two techniques in this fashion and this investigation was designed in part to provide such a perspective.

Currently, we usually have the luxury of being able to perform both Doppler echocardiography and cardiac catheterization in the evaluation of patients with valvular heart disease, but financial pressure is building to eliminate duplicate studies provided by competing technologies. As newer and often expensive technology is introduced, these pressures can be expected to increase. Since these patients were studied, the echocardiographic equipment has improved. Currently, transesophageal echocardiography, ECG-gated magnetic resonance imaging and first pass and equilibrium radionuclide analysis offer new approaches to the assessment of patients with valvular heart disease and each promises improved diagnostic accuracy. However, as these new techniques are evaluated, it will be important not only to provide data that compare their ability to describe each patient's pathophysiology with that of older techniques, but also to explore the impact of new diagnostic techniques on actual clinical management and patient outcome.

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